



National Aeronautics and
Space Administration



Emergency Locator Transmitter Survivability & Reliability (ELTSAR) *Phase 2: Crash Safety*

**Briefing to SC-229/WG-98
CNES Toulouse
3-5 Sept 2014**

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Current Test

- RTCA DO-204A, Paragraph 2.6.3.2
- ELT and mounting tray are rigidly mounted to a shock tester and exposed to a series of 6 shock pulses
 - Half-sine, 100 G, 23 ms
 - Uni-axial (up, down, fore, aft, side (2))
- The unit must pass aliveness testing following the test series

Vendor Setup



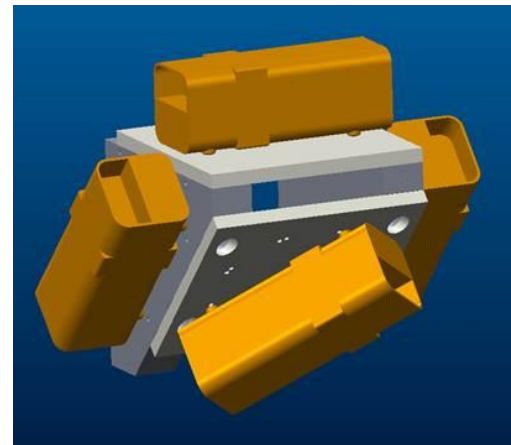
LaRC Facility



Rationale for Modification

- Typical airplane crash pulse duration is much longer (>100 ms)
- Crash environment includes simultaneous multi-axis loading
- Current test did not identify failure mode of ejected ELTs
- Need a test that is more representative of actual crashes for future designs or any configuration

ELTSAR multi-axis test fixture



➤ Detailed investigation reports from relatively recent crashes show that ELT systems continue to fail due to the beacon being ejected from its mounting tray

- NTSB [AAR-11/03](#), 9 Aug 2010 (left, Stevens/O'Keefe)
- TSB of CA Report #[A11W0151](#), 4 Oct 2011 (right)
- NTSB Accident #[WPR12FA184](#), 25 Apr 2012
- NTSB Accident #[CEN12FA080](#), 23 Nov 2011





Hook and loop fasteners (Velcro straps) are not accepted for qualification of NEW designs as of 11/26/2012



Department of Transportation
Federal Aviation Administration
Aircraft Certification Service
Washington, D.C.

TSO-C126b
Effective
Date: 11/26/12

Technical Standard Order

Subject: 406 MHz Emergency Locator Transmitter (ELT)

1. **PURPOSE.** This technical standard order (TSO) is for manufacturers applying for a TSO authorization (TSOA) or letter of design approval (LODA). In it, we (the Federal Aviation Administration, (FAA)) tell you what minimum performance standards (MPS) your 406 MHz ELT must first meet for approval and identification with the applicable TSO marking.
2. **APPLICABILITY.** This TSO affects new applications submitted after its effective date.
 - a. All prior revisions to this TSO are no longer effective. Generally, we will not accept applications for the previous revision after the effective date of this TSO. We may do so, however, up to six months after it, if we know that you were working against the prior MPS before the new change became effective.
 - b. 406 MHz ELTs approved under a previous TSOA may still be manufactured under the provisions of its original approval.
3. **REQUIREMENTS.** New models of 406 MHz ELTs identified and manufactured on or after the effective date of this TSO must meet the MPS qualification and documentation requirements in RTCA Inc. document, RTCA/DO-204A, *Minimum Operational Performance Standards (MOPS) for 406 MHz Emergency Locator Transmitters (ELTs)*, dated December 6, 2007, sections 2.2 and 2.4. The 406 MHz ELT must include a 121.5 MHz homing beacon. We also require that you obtain a Cospas-Sarsat type approval certificate before applying for this TSO. Additionally, the use of hook and loop fasteners is not an acceptable means of attachment in complying with the Crash Safety requirements of section 2.2.5 of RTCA/DO-204A for automatic fixed (AF) and automatic portable (AP) ELTs.



NASA TP 2083 (1970's GA Crash Testing)

Crash Pulse - Vertical Direction



Test	Flight-path angle, γ , deg	Pitch angle, θ , deg	Flight-path velocity, V_{fp} , m/sec	Experimental normal pulse parameters			
				Maximum deceleration, $\ddot{z}_{a,max}$, g units	Pulse duration, Δt , sec	Velocity change, ΔV_z , m/sec	Impulse, $\ddot{z}_{a,max} \Delta t$, sec
2	-16	-12	27	20	0.089	8.5	1.78
3	-18.75	-18	26.2	28	.05	8.74	1.40
4	-15	4	27	16	.102	8.5	1.63
5	-20.5	-19.5	26.1				
6	-16	14	27	18	.110	10.4	1.98
7	-47.5	-47.25	28.6	20	0.174	20.73	3.48
8	-30	-31	27	18	.135	13	2.43
9	-16	-13	26.3				
10	-18	-14	27.8				
11	-31	-27	25	12	.132	10	1.58
12	-15	9	25	12	0.149	9.5	1.79
13	-29	-26	25	27	.049	13	1.32
14	-16.75	-11.75	32.7				
15	-18	-12	41	46	.064	17	2.94
16	-15	-4	40	46	.054	15	2.48
17	-30	-38	40	42	0.097	19	4.07
18	-30	-31	27.9	27.2	.083	11.3	2.26
19	-15	-17.7	27	16	.12	10.6	1.92
20	-15.4	2	26.6	31	.057	9.1	1.77
21	-30	-29.5	27.1	29.9	.096	12.3	2.87
FAA-1	-32	-30	25	21	0.120	11	2.52
FAA-2	-17	-13.5	23	7	.160	6	1.12
FAA-3	-34.5	-39	25.9	18	.12	13.8	2.2
FAA-4	-32	-34.5	25.3	18	.13	14.8	2.34

AVERAGE: **24 G** **105 ms** **12 m/s**

LandIR Overview



NASA TP 2083 (1970's GA Crash Testing)

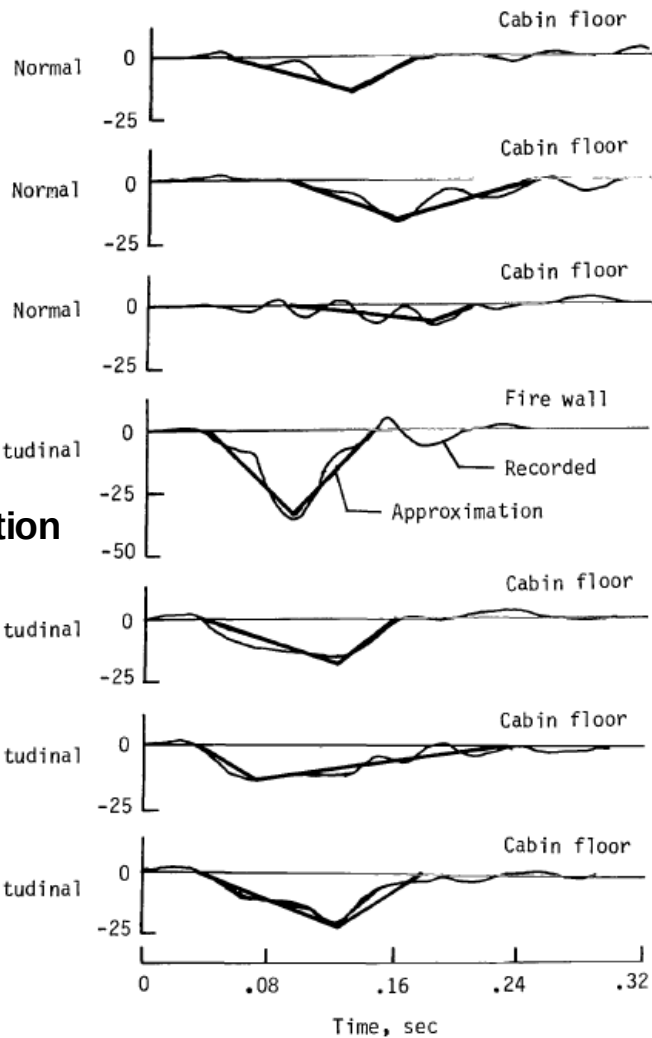
Crash Pulse - Longitudinal Direction



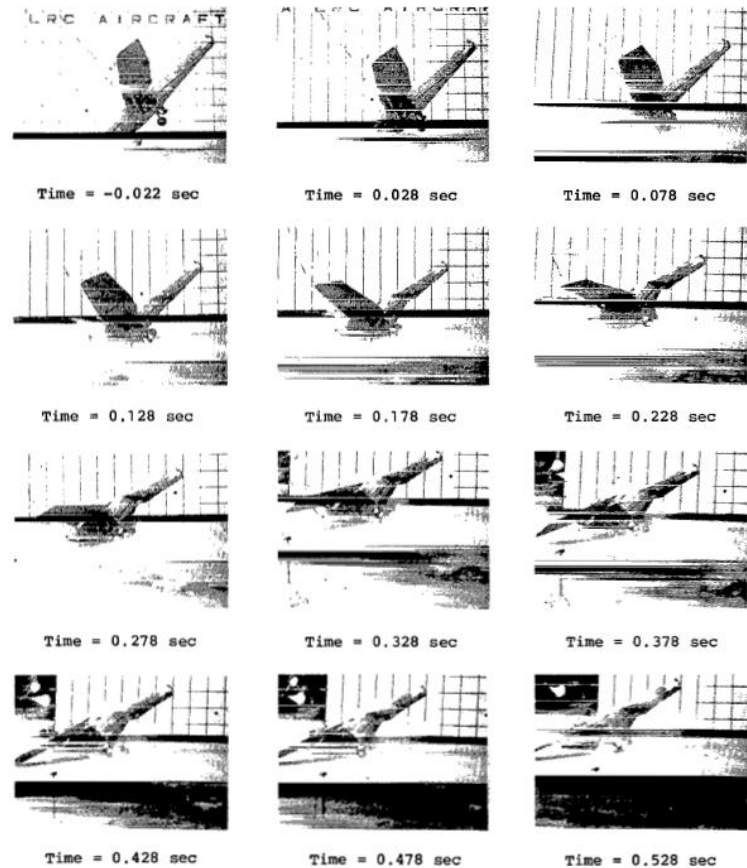
Test	Flight-path angle, γ , deg	Pitch angle, θ , deg	Experimental longitudinal pulse parameters				
			Flight-path velocity, V_{fp} , m/sec	Maximum deceleration, $\ddot{x}_{a,max}$, g units	Pulse duration, Δt , sec	Velocity change, ΔV_1 , m/sec	Impulse $\ddot{x}_{a,max} \Delta t$, sec
2	-16	-12	27	19	0.06	6	1.14
3	-18.75	-18	26.2	18	.044	4.3	.79
4	-15	4	27	7	.101	5	.71
5	-20.5	-19.5	26.1				
6	-16	14	27	8	.110	3.1	.86
7	-47.5	-47.25	28.6	8.8	0.144	^a 4.6; 6.8; 9	1.27
8	-30	-31	27	16	.110	6	1.76
9	-16	-13	26.3				
10	-18	-14	27.8				
11	-31	-27	25	28	.138	17.7	3.86
12	-15	9	25	4	0.060	1.2	0.24
13	-29	-26	25	11	.093	5	1.02
14	-16.75	-11.75	32.7				
15	-18	-12	41	16	.058	5	.93
16	-15	-4	40	12	.062	4	.744
17	-30	-38	40	22	0.068	10	1.5
18	-30	-31	27.9	15.2	.090	8.2	1.37
19	-15	-17.7	27	5.5	.088	4	.48
20	-15.4	2	26.6	6.4	.052	1.9	.333
21	-30	-29.5	27.1	14	.112	10.5	1.57
FAA-1	-32	-30	25	22	0.110	8	2.42
FAA-2	-17	-13.5	23	3.5	.060	1.5	.21
FAA-3	-34.5	-39	25.9	17	.13	12	2.21
FAA-4	-32	-34.5	25.3	45	.10	21.5	4.5

AVERAGE: 15 G 90 ms 7 m/s

NASA TP 2083 (1970's GA Crash Testing) Sample Time Histories

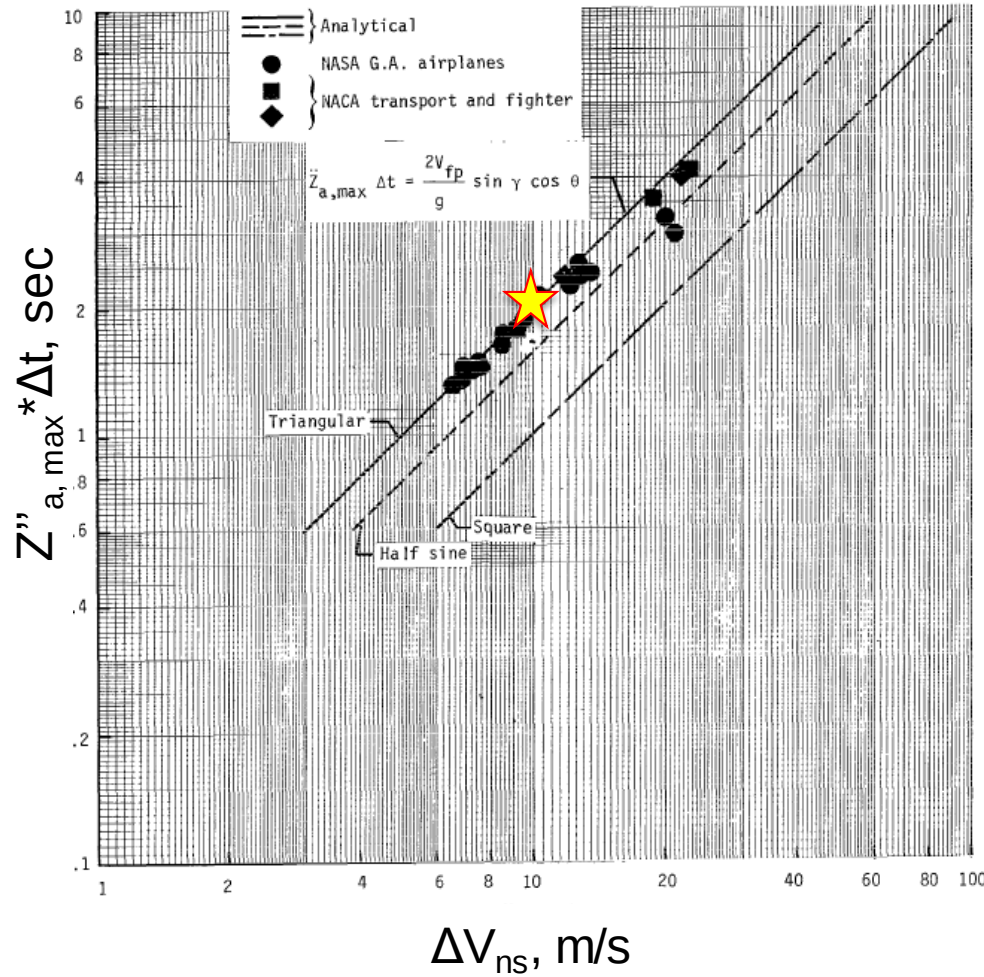


(b) Decelerations.



Note relative amplitude of normal (vertical) and longitudinal deceleration

NASA TP 2083 (1970's GA Crash Testing) Impulse Data



- Vertical shown, longitudinal similar
- For reference, impact velocity for a 100 G, 20 ms pulse is 10 m/s (33 ft/s) as shown
- DO-204A requirement
 - The total energy associated with the 100 G, 23 ms half-sine pulse appears reasonable
 - Velocity requirement is needed
 - There may be a disconnect in how the crash energy is obtained (high G's for short duration)
- Lower G's for longer duration can be more injurious to passengers and are more common of airplane crashes

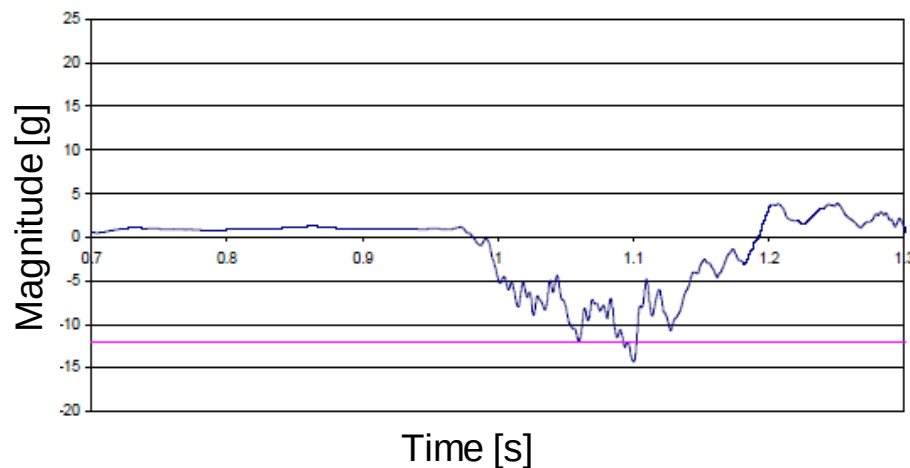
FAA Full Aircraft Vertical Drop Test ATR42-300, July 2003

- **Drop Height:**
 - 14 ft (4.3 m)
- **Impact Velocity:**
 - 30 ft/s (9.1 m/s)
- **Airplane Weight (Mass):**
 - 33,200 lbs (15,060 kg)
- **Acceleration Amplitude:**
 - 15 Gs
- **Pulse Duration:**
 - 200 ms

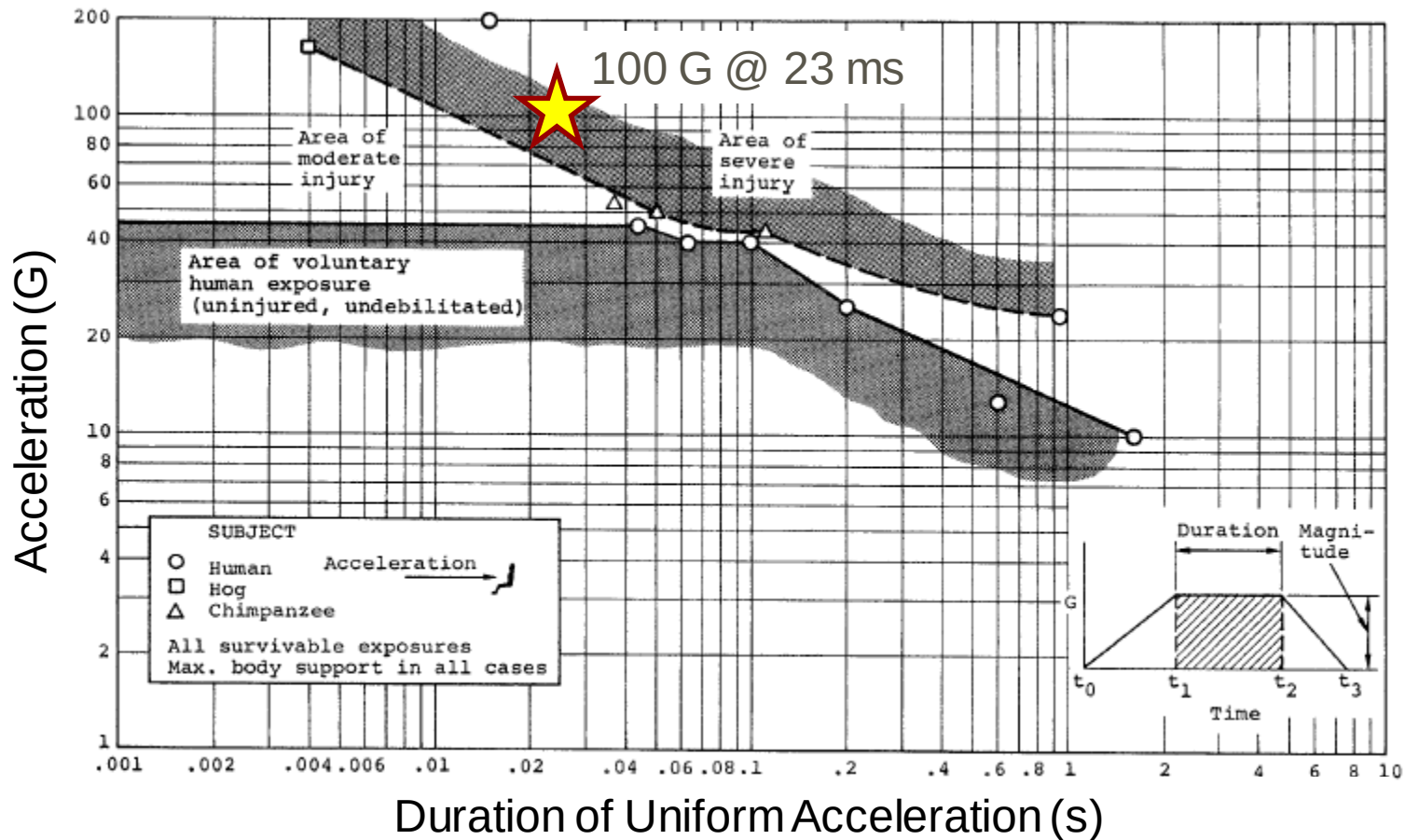
“Development of an Enhanced Emergency Locator Transmitter for General Aviation”,
Rowan University, Sept. 2006



- Pre-drop (left)
- Post-drop (right)
- Accelerometer time history, vertical orientation, tail section (bottom)



Human Tolerance to Injury Longitudinal Direction



“Small Airplane Crashworthiness Design Guide”, Prepared by Simula Technologies for NASA LaRC, April 2002

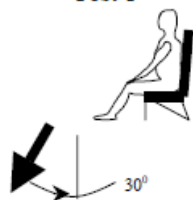
FAA AC No. 25.562-1B Seat Test Requirements

- Transport seat testing requirement shown for reference
- Note pulse characteristics
 - Rise Time: 80-90 ms
 - Multi-axis inputs
 - Velocity: 11-13 m/s (35-44 ft/s)
 - Amplitude: 14-16 G
- Multi-axis inputs at lower G's for longer duration than specified by DO-204A

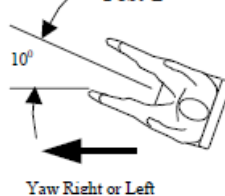
Illustration shows a forward facing seat

Inertial load shown by arrow

Test 1



Test 2



Min V_1 m/s (ft./s)

10.67 (35)

13.41 (44)

Max t , s

0.08

0.09

Min G

14

16

Deform Floor

Degrees Roll

0

10

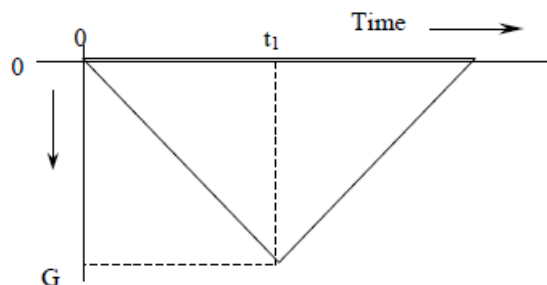
Degrees pitch

0

10

Test Pulse simulating
Aircraft Floor
Deceleration -Time
History

Deceleration



t_1 =Rise time

V_1 = Impact velocity

The ideal pulse is a symmetrical isosceles triangle



Summary of FAA Seat Test Requirements for Various Categories



Table 7-1.

Dynamic Test Requirements for 14 CFR 23, 25, 27, and 29 (References 7-1, 7-7 – 7-26)

TEST 1	FAR 23	FAR 25	FAR 27	FAR 29
Min velocity (ft/sec)	31	35	30	30
Max time to peak (sec)	0.05/0.06	0.08	0.031	0.031
Min G	19/15	14	30	30
Seat pitch angle (deg)	30	30	30	30
Seat yaw angle (deg)	N/A	N/A	N/A	N/A
Roll (deg)	0	0	10	10
Pitch (deg)	0	0	10	10
TEST 2	FAR 23	FAR 25	FAR 27	FAR 29
Min velocity (ft/sec)	42	44	42	42
Max time to peak (sec)	0.05/0.06	0.09	0.071	0.071
Min G	26/21	16	18.4	18.4
Seat pitch angle (deg)	N/A	N/A	N/A	N/A
Seat yaw angle (deg)	10	10	10	10
Roll (deg)	10	10	10	10
Pitch (deg)	10	10	10	10

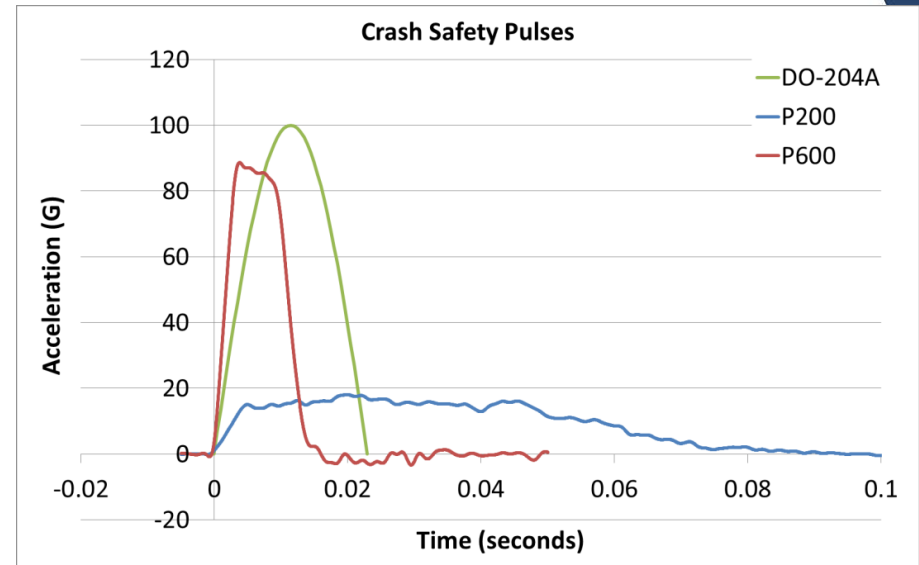
“Small Airplane Crashworthiness Design Guide”, Prepared by Simula Technologies for NASA LaRC, April 12, 2002

➤ Two different pulses utilizing two different types of Energy Absorbing (EA) foam

- Lower Density Foam – **P200**
- Higher Density Foam – **P600**

➤ Impact velocity ~ 20 ft/s (6 m/s)

- Higher velocity is achievable but requires the use of a much higher density EA foam from another vendor



- LaRC used EA foam because of experience with the material
- Total energy associated with EA foam pulses is lower than the current requirement but peak G-levels are maintained for a longer period of time
- Trapezoidal pulse shape is in good agreement with 2013 LaRC crash testing



Crash Pulse Summary



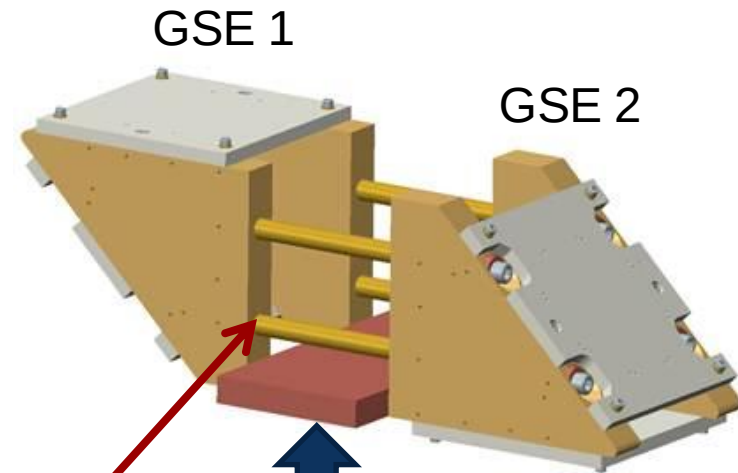
	DO-204A Requirement	LaRC Drop Tower P600 EA Foam		LaRC Drop Tower P200 EA Foam	NASA TP 2083 (Longitudinal)
Amplitude (G)	100	86		16	15
Duration (ms)	23	15		85	90

➤ The goal for the P600 pulse was to recreate the DO-204A required pulse. The extent to which that was possible was limited by material characteristics

➤ The P200 pulse was designed to mimic the average longitudinal pulse recorded in 1970's crash testing of GA airplanes at LaRC

Ground Support Equipment (GSE) for Multi-axis Crash Safety Testing

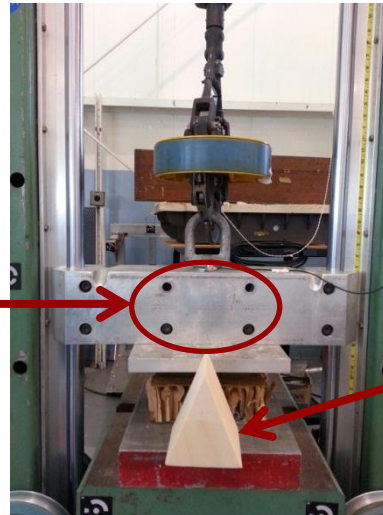
- Up to 8 ELTs can be tested simultaneously
- Mounting orientations in all combos of pitch/roll/yaw at 45° increments



Impacting Surface

4 hole interface
between drop
mass and GSE

LaRC Facility



EA foam

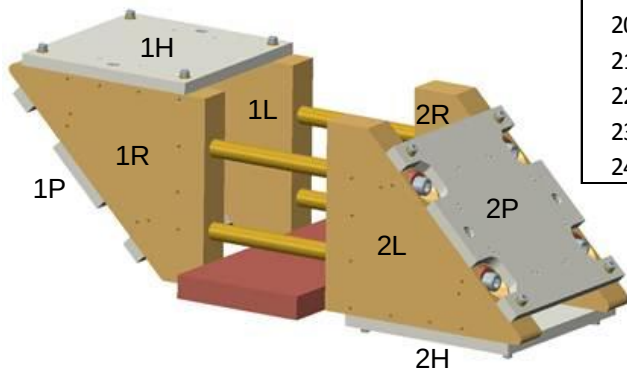
GSE 1 with 4 ELTs



Crash Safety Test Matrix

12 Orientations per Pulse

- Current shock & crash safety test protocol calls for 12 tests
- 12 orientations per pulse (EA foam)
- 180° different orientations used for repeats



Drop ID	EA Foam	GSE 1						GSE 2					
		1H	1L (deg)	1R (deg)	1P (deg)	2H	2L (deg)	2R (deg)	2P (deg)				
1	P200		ELT 1 0		ELT 2 0		ELT 3 0		ELT 4 0				
2	P600		ELT 1 0		ELT 2 0		ELT 3 0		ELT 4 0				
3	P200		ELT 1 45		ELT 2 45		ELT 3 135		ELT 4 45				
4	P600		ELT 1 45		ELT 2 45		ELT 3 135		ELT 4 45				
5	P200		ELT 1 90		ELT 2 90		ELT 3 90		ELT 4 90				
6	P600		ELT 1 90		ELT 2 90		ELT 3 90		ELT 4 90				
7	P200			ELT 2 0	ELT 1 0			ELT 4 0	ELT 3 0				
8	P600			ELT 2 0	ELT 1 0			ELT 4 0	ELT 3 0				
9	P200			ELT 2 135	ELT 1 45			ELT 4 45	ELT 3 45				
10	P600			ELT 2 135	ELT 1 45			ELT 4 45	ELT 3 45				
11	P200			ELT 2 90	ELT 1 90			ELT 4 90	ELT 3 90				
12	P600			ELT 2 90	ELT 1 90			ELT 4 90	ELT 3 90				
13	P200	ELT 1			ELT 4 0	ELT 3			ELT 2 0				
14	P600	ELT 1			ELT 4 0	ELT 3			ELT 2 0				
15	P200			ELT 1 135	ELT 4 45		ELT 3 135		ELT 2 45				
16	P600			ELT 1 135	ELT 4 45		ELT 3 135		ELT 2 45				
17	P200	ELT 3			ELT 4 90	ELT 1			ELT 2 90				
18	P600	ELT 3			ELT 4 90	ELT 1			ELT 2 90				
19	P200	ELT 2			ELT 3 0	ELT 4			ELT 1 0				
20	P600	ELT 2			ELT 3 0	ELT 4			ELT 1 0				
21	P200		ELT 2 45		ELT 3 45			ELT 4 45	ELT 1 45				
22	P600		ELT 2 45		ELT 3 45			ELT 4 45	ELT 1 45				
23	P200	ELT 4			ELT 3 90	ELT 2			ELT 1 90				
24	P600	ELT 4			ELT 3 90	ELT 2			ELT 1 90				

Goal is to identify a worst-case set of orientation(s) and pulse(s), while maintaining connection to real-world crash data



Results



➤ TBD

- Testing to be conducted September 2014
- Drop mass acceleration time histories will be recorded
- Tests will be recorded with a high-speed video camera
- Co-axial output will be fed to a spectrum analyzer to confirm activation and signal characteristics
- Additional crash pulses may be developed and tested as results dictate



Summary



- Although the current qualification standard for ELT designs prohibits the use of hook and loop fasteners, the Crash Safety Test protocol remains unchanged
- In order to ensure robustness in future designs, a Crash Safety Test should be designed that would have identified the failure mode of ELTs ejecting from their mounting trays in the field
- NASA will perform modified Crash Safety Testing of multiple ELT designs in order to investigate the effects of simultaneous multi-axis loading and varying pulse duration in the Summer/Fall 2014
- Rationale for pulse-forms will be based on real-world crash data
- The modified test series will include designs that utilize hook and loop fasteners in order to positively identify a set of test parameters that may demonstrate the failure mode
- Recommendations for a modified Crash Safety Test protocol will be made to RTCA SC-229 based on test findings





BACKUP